DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Improvement of Reliability Indices in a Micro-grid System involving Renewable Generation and Energy Storage

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Introduction and Motivation

- The demand for energy continues to rise. Electrical energy makes up 12% of the total energy processed by humanity, and it is expected to grow over the next few years (34% predicted for 2025) [1].
- Concerns regarding the depletion of traditional energy sources and the declining health of the environment make incorporating alternative energy sources such as renewables into the grid critical.
- In order for renewable generation to be incorporated on a large scale, utilities must be able to guarantee that customers receive adequate and quality power, constituting a reliable system [2].

Energy Consumption and Production in the United States (Quadrillion BTU) 1949-2014

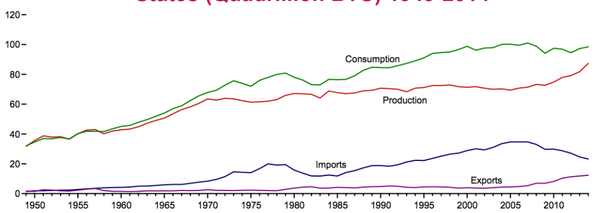

Fig. 1: This graph depicts the growing the demand for energy in the United States [3]. Consumption has steadily increased over the last 60 years.

Primary Energy Consumption in the United States (Quadrillion BTU) 1949-2014

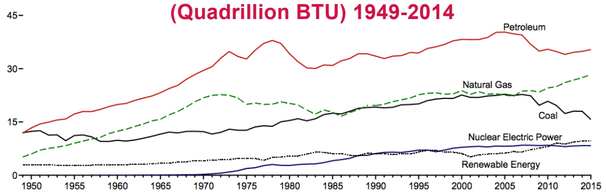

Fig. 2: This graph depicts the energy consumption by source in the United States [3]. As the demand for energy continues to rise, renewable energy sources will continue to be used at higher rates each year in order to meet the demand.

Research Goals

- Ensuring the reliability of a grid system that includes unpredictable sources of generation, such as wind and solar, is studied using a small-scale system called a micro-grid.
- The goal of this study is to improve the reliability indices of the system with the incorporation of energy storage, such as batteries, into the micro-grid.

Method

- A linear optimization model of the problem is shown that maximizes the reliability of the system by determining the number of critical and non-critical loads that can be satisfied at each time step.
- The maximization of the number of loads is constrained by the available generation in the system at each specific time step.
- Gurobi with CVX using MATLAB is used to solve the optimization problem and analyze the results.
- The System Average Interruption Frequency Index (SAIFI) was calculated for the micro-grid system and compared with a traditional distribution system SAIFI index [2].

Mathematical Model

The following mathematical model maximizes the number of loads that are met at each time step.

$$\max \quad \sum_{t=0}^{T}(\omega_1 \sum_{i\in\mathcal{N}_i} x_i L_i + \omega_2 \sum_{j\in\mathcal{N}_j} y_j L_j) - \omega_3 P_{ES}(t)$$
$$\text{s.t} \sum_i x_i L_i + \sum_j y_j L_j \le P_G(t)$$
$$P_{WTG}(t) + P_{PV}(t) + P_{ES}(t) = P_G(t)$$
$$0 \le P_{WTG}(t) \le P_{WTGMax}(t)$$
$$0 \le P_{PV}(t) \le P_{PVMax}(t)$$
$$0 \le P_{ES}(t) \le P_{ESMax}(t)$$

$$x_i = \begin{cases} 0 \text{ if load is not met} \\ 1 \text{ if load is met} \end{cases} \qquad y_j = \begin{cases} 0 \text{ if load is not met} \\ 1 \text{ if load is met} \end{cases}$$

$P_{WTG}(t)$: power from wind turbine at time step t (MW)
$P_{PV}(t)$: power from solar at time step t (MW)
$P_{ES}(t)$: power from energy storage at time step t (MW)
$P_G(t)$: Total power generation at time step t (MW)
t: time step
T: Time period for example one day
L_i: critical load values (MW)
L_j: non-critical load values (MW)
n_{loads}: all loads
$\mathcal{N}_i$: set of critical loads
$\mathcal{N}_{ni}$: set of non-critical loads
ω_1: cost of critical loads
ω_2: cost of non-critical loads
ω_3: cost of energy storage

$$SAIFI = \frac{\sum_{i\in\mathcal{N}_i} x_i + \sum_{j\in\mathcal{N}_j} y_j}{n_{loads}} \qquad (1)$$

Assumptions

- The capacity of the lines are infinite
- Power losses are negligible

Micro-grid System

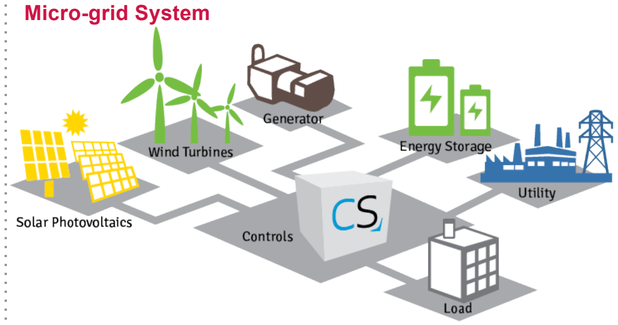

Fig. 3: This image shows the components of a micro-grid system including, renewable energy sources and energy storage [5]. The mathematical model assumes a micro-grid. In the future work, the problem can be expanded to a distribution system.

Results

- The results show the available generation at each time step and the critical and non-critical loads that can be satisfied at these time steps.
- The system uses two wind turbines, two solar panels, 450 critical loads, and 250 non-critical loads [2].
- The rated power for each wind turbine and solar panel is 2000kW. The rated power for each critical load is 10kW and for each non-critical load is 4kW [2]. The rated power for the energy storage is 400kW.

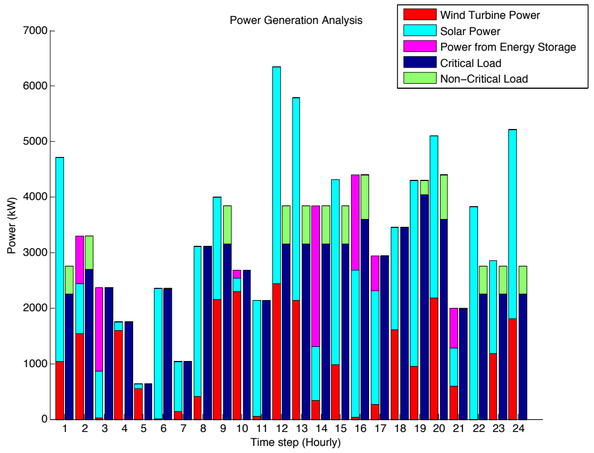

Fig. 4: This figure shows the available generation, critical, and non-critical loads at each time step. The goal is to balance the available generation with the maximum number of loads.

Conclusion

The results show that the SAIFI index improves in the micro-grid system when energy storage was incorporated into the system.

Time Step	SAIFI with Energy Storage	SAIFI without Energy Storage
1	1	1
2	1	0.581
3	0.564	0.206
4	0.417	0.417
5	0.153	0.151
6	0.561	0.561
7	0.214	0.213
8	0.556	0.556
9	1	1
10	0.549	0.517
11	0.437	0.436
12	1	1
13	1	1
14	1	0.269
15	1	1
16	1	0.479
17	0.527	0.414
18	0.494	0.493
19	0.743	0.743
20	1	1
21	0.476	0.307
22	1	1
23	1	1
24	1	1

Fig. 5: This table shows the results of the SAIFI index for a system that includes energy storage and a system that does not include energy storage. The index at each time step is maintained or improved when energy storage is incorporated into the system.

Future Work

- In the future, the power losses need to be taken into consideration, which involves nonlinear power flow techniques.
- Currently, a topology for this system is being developed and tested using DC Optimal Power Flow.
- Finally, the system can be expanded to include more sources, loads, and a connection to the main grid.

Bibiliography

[1] H. Ibrahim, A. Ilinca, and J. Perron, "Energy storage systems-Characteristics and comparisons," *Renew. Sustain. Energy Rev.*, vol. 12, no. 5, pp. 1221–1250, 2008.
[2] O. A. Ansari, N. Safari, and C. Y. Chung, "Reliability assessment of microgrid with renewable generation and prioritized loads," *IEEE Green Energy Systems Conference,* pp. 1–6, Nov. 2016.
[3] U.S. D. of Energy, "Monthly Energy Review: Electricity U.S. Energy Information Administration," March 31 2015.
[4] L. Zhi-jian, W. Gui-hong, Y. Dong-hui, and S. Qi, "Reliability assessment of distribution network considering the randomness of distributed generation," *IEEE China International Conference on Electricity Distribution*, pp. 1–6, 2016.
[5] INBC Global Ltd., "Distributed Generation and Energy Storage," 2008.
[6] H. Oh, "Optimal planning to include storage devices in power systems," *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 1118–1128, 2011.

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